

## PATENT ABSTRACTS OF JAPAN

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(71)Applicant : TOYODA GOSEI CO LTD  
AKASAKI ISAMU  
AMANO HIROSHI

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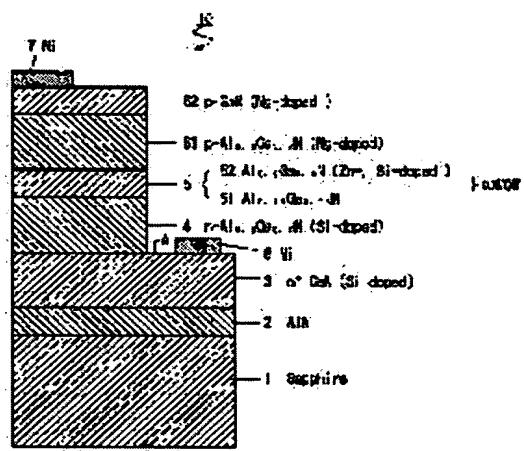
(72)Inventor : ASAMI SHINYA  
KOIKE MASAYOSHI  
AKASAKI ISAMU  
AMANO HIROSHI

(54) GROUP-III NITRIDE SEMICONDUCTOR LIGHT-EMITTING DEVICE

(57)Abstract:

**PROBLEM TO BE SOLVED:** To obtain high luminance emission from green to blue and to obtain the emission of various colors only with a group-III nitride semiconductor.

**SOLUTION:** A light emitting diode 10 is constituted by a sapphire substrate 1, a buffer layer 2, a high carrier density n+ layer 3, an n-layer 4 made of Al0.3Ga0.7N, a light-emitting layer 5, a p-layer 61 made of Al0.3Ga0.7N and doped with Mg, a contact layer 62 made of GaN and doped with Mg, an electrode 7 made of Ni and an electrode 8. The light-emitting layer 5 has a multiplex quantum well structure where the barrier layer 51 of six layers, which is made of Al0.25Ga0.75N whose film thickness is about 100&angst;, and the barrier well layer 52 of five layers, which is made of Al0.2Ga0.8N whose film thickness is 100&angst;, are alternately formed. Zinc and silicon are added to the density of  $5 \times 10^{18}/\text{cm}^3$  to the well layer 52. The light-emitting layer 5 emitting such ultraviolet rays and a fluorescent substance layer receiving the ultraviolet rays which the light-emitting layer 5 radiates and converting it into the visible light on the electrode 7 are provided.



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## CLAIMS

## [Claim(s)]

[Claim 1] The light emitting device characterized by preparing the luminous layer which emits light in ultraviolet rays, and the fluorescent substance layer which receives said ultraviolet rays to which said luminous layer emanates, and is changed into the light in the light emitting device which used 3 group nitride semi-conductor for the luminous layer.

[Claim 2] Said fluorescent substance layer is a light emitting device according to claim 1 characterized by being formed in the lens object for emitting light outside.

[Claim 3] It is the light emitting device according to claim 1 which has an electrode layer for supplying electric power to said luminous layer, and is characterized by forming said fluorescent substance layer on the electrode layer.

[Claim 4] It is the light emitting device according to claim 1 which has silicon on sapphire for forming said luminous layer, and is characterized by said fluorescent substance layer being formed in the field of the opposite side by the formation side of said luminous layer of the silicon on sapphire.

[Claim 5] Said fluorescent substance layer is a light emitting device according to claim 1 characterized by being formed in the side face of said luminous layer.

[Claim 6] Alx2GaY2In1-X2-Y2N with forbidden-band width of face wider than the well layer to which said luminous layer changes from Alx1GaY1In1-X1-Y1N, and this well layer from — light emitting device according to claim 1 characterized by having consisted of quantum wells to which the laminating of the barrier layer which changes was carried out alternately [ at least one or more layer ], and adding acceptor impurity and a donor impurity to said luminous layer.

[Claim 7] The light emitting device according to claim 6 characterized by said both acceptor impurity and said donor impurities being added by each well layer or each well layer, and each barrier layer of said luminous layer.

[Claim 8] The light emitting device according to claim 6 characterized by said acceptor impurity and said donor impurity being added by turns by the well layer which said luminous layer adjoins.

[Claim 9] The light emitting device according to claim 6 to which said acceptor impurity is characterized by for said donor impurity being added by said well layer, and said acceptor impurity being conversely added for said donor impurity by said barrier layer at said barrier layer of said luminous layer, respectively at said well layer of said luminous layer.

[Claim 10] said barrier layer — GaN from — light emitting device according to claim 6 characterized by changing.

[Claim 11] Said well layer and said barrier layer are a light emitting device according to claim 6 characterized by the lattice constant being in agreement.

[Claim 12] Said luminous layer is inserted by p layers of p conduction type, and n layers of n conduction type, and is thickly constituted from diffusion length of an electron hole. Alx3GaY3In1-X3-Y3N by which the becoming donor impurity with which said luminous layer and lattice constant spread said n layers in abbreviation etc. was added It constitutes from a semi-conductor. The light emitting device according to claim 1 characterized by constituting from an Alx4GaY4In1-X4-Y4N semi-conductor with which acceptor impurity with larger forbidden-band width of face than said luminous layer was added as enough to shut up the electron into which said p layers were poured by said luminous layer.

[Claim 13] Said n layers are GaN by which said luminous layer was constituted from GaY5In1-Y5N (0.92 <= Y5 <= 1), and the donor impurity was added. Light emitting device according to claim 11 characterized by being constituted.

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## DETAILED DESCRIPTION

## [Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the semi-conductor light emitting device using 3 group nitride semi-conductor which can set the luminescent color as arbitration.

[0002]

[Description of the Prior Art] InGaN from which blue luminescence is obtained conventionally. The used semi-conductor light emitting device is known. Furthermore, in order to obtain green luminescence of long wavelength more by this light emitting device, and to narrow forbidden-band width of face of a luminous layer, enlarging the presentation ratio of In is performed.

[0003]

[Problem(s) to be Solved by the Invention] However, if the presentation ratio of In is enlarged, the crystallinity of a luminous layer will get worse and luminescent efficiency will fall. Therefore, it takes for lengthening luminescence wavelength, luminescence brightness becomes low, and green luminescence is not yet obtained from the blue of high brightness. Moreover, when various kinds of luminescent color was obtained, the semiconductor material of forbidden-band width of face was used for the wavelength of the luminescent color considerable the bottom.

[0004] This invention is only 3 group nitride semi-conductor, and is obtaining luminescence of various kinds of colors while it accomplishes in order to solve the above-mentioned technical problem, and the purpose obtains green luminescence from the blue of high brightness.

[0005]

[Means for Solving the Problem] According to invention of claim 1, the luminous layer using 3 group nitride semi-conductor which emits light in ultraviolet rays, and the fluorescent substance layer which receives the ultraviolet rays to which the luminous layer emanates, and is changed into the light are prepared. Therefore, since a fluorescent substance is excited by the ultraviolet rays of wavelength shorter than the light, it can only change the quality of the material of a fluorescent substance, and can obtain the light of various kinds of colors.

[0006] The ultraviolet rays from a luminous layer are changed into the light by the fluorescent substance layer by which invention of claim 2 was formed in the lens object, the fluorescent substance layer by which invention of claim 3 was formed on the electrode layer, the fluorescent substance layer formed in the silicon-on-sapphire side where invention of claim 4 is transparent, and the fluorescent substance layer by which invention of claim 5 was formed in the side face of a luminous layer. All can change the luminescent color only by changing the class of fluorescent substance of a fluorescent substance layer.

[0007] Claims 6-13 are related with the luminous layer which emits ultraviolet rays. By invention of claims 6-11, it is AlGaN about a luminous layer. It considered as the quantum well structure which carried out the at least one or more layer laminating, and a donor impurity or acceptor impurity was added to the luminous layer. For this reason, since the recombination probability of the electron contributed to luminescence since donor level or acceptor level is formed, and a hole increases, the luminescent efficiency by recombination improves. Moreover, the presentation ratio and high impurity concentration of an indium are determined by the relation between the emission peak wavelength to wish and luminescence reinforcement.

[0008] Especially, it is InGaN to a luminous layer. Crystalline good AlGaN It uses, and by using a luminous layer as the distorted superlattice of quantum well structure, propagation of the misfit of a lattice constant was able to be prevented, the crystallinity of a well layer was able to be raised, and, thereby, luminescent efficiency was able to be raised. Especially, both acceptor impurity and a donor impurity were able to be added in the crystalline good well layer, and the luminescent efficiency of ultraviolet rays was able to be greatly raised by opposite luminescence by acceptor level and donor level.

[0009] In addition, the mol presentation ratio of aluminum of a luminous layer considers as 15% or more, and the thickness of a well layer has the desirable range of 50A ~ 200A. Since the quantum effectiveness stops occurring when impurity diffusion will happen if it is 50A or less, and it is 200A or more, it is not desirable. Moreover, the thickness of a barrier layer has the desirable range of 50A ~ 200A. Since the effectiveness which confines a carrier in a well layer will fall if it is 50A or less, since the quantum effectiveness stops occurring when it is 200A or more, it is not desirable desirably. Since resistance becomes large in the case of a non dope, and the crack by the rearrangement will enter when it dopes if it is 200A or more, it is not desirable.

[0010] Moreover, the concentration of the acceptor impurity added to a luminous layer and a donor impurity is three to  $1 \times 10^{20}/\text{cm}^3$  of  $1 \times 10^{17}/\text{cm}$ . The range is desirable.  $1 \times 10^{17}/\text{cm}^3$  Luminous efficiency falls that it is the following with the lack of an emission center, and it is  $1 \times 10^{20}/\text{cm}^3$ . If it becomes the above, since crystallinity will worsen and the Auger effect will occur, it is not desirable.

[0011] Moreover, so that a luminous layer and a lattice constant may spread abbreviation etc. and n layers may become in invention of claim 12 Alx3GaY3In1-X3-Y3N presentation ratios X3 and Y3 They are the Alx4GaY4In1-X4-Y4N presentation ratios X4 and Y4 so that p layers may fully shut up the electron poured in from n layers to the luminous layer and forbidden-band width of face may become large by being determined only in \*\*\*. It is determined. Thus, by determining n layers, there is little misfit by difference of the lattice constant of n layers and a luminous layer, and the crystallinity of a luminous layer improves.

[0012] The obstruction by junction to n layers and a luminous layer carries out the operation which shuts up the electron hole poured into the luminous layer from p layers. However, the diffusion length of an electron hole is several 1000A, and the luminous layer consists of the diffusion length thickly. therefore, the obstruction by junction to n layers and a luminous layer — the inside of the luminous layer of an electron hole — it does not contribute effective in shutting up. therefore — since the obstruction between n layers and a luminous layer may be small — n layers — a luminous layer — receiving — a lattice constant — abbreviation — it becomes equal — as — Alx3GaY3In1-X3-Y3N presentation ratios X3 and Y3 By determining, the grid mismatching between n layers and a luminous layer can be made small as much as possible, and it becomes possible to raise the crystallinity of a luminous layer. Consequently, the luminous efficiency of ultraviolet rays improves.

[0013] the case where a luminous layer is constituted from GaY5In1-Y5N ( $0.92 \leq Y \leq 1$ ) since light is emitted in ultraviolet rays — n layers — GaN \*\*, by carrying out, grid mismatching can be made small.

[0014] moreover, GaN by which silicon was added by the high concentration which the above-mentioned light emitting diode forms a buffer layer on

silicon on sapphire, and functions as a lead of the contact over n layers on it from — n+ which changes A layer can also be formed. In this case, it is GaN about n layers. By constituting, it is n+. The lattice constant of a layer and n layers is completely in agreement, and a misfit rearrangement is not generated. Therefore, the crystallinity of a luminous layer improves more.

[0015]

[Embodiment of the Invention] The structure of the light emitting diode which emits light in ultraviolet rays is explained. In drawing 1, light emitting diode 10 has silicon on sapphire 1, and it is AlN of 500 \*\* on the silicon on sapphire 1. The buffer layer 2 is formed. the buffer layer 2 top — order — thickness 2.0 [ about ] mum and silicon dope GaN of 2x1018/of concentration of electrons cm 3 from — high carrier concentration n+ which changes A layer 3 and thickness 1.0 [ about ] mum — concentration of electrons aluminum0.3Ga0.7N of the silicon dope of 2x1018-/cm3 from — n layers of 4 and the luminous layers 5 of about 0.11 micrometers of all thickness which change, and thickness 1.0 [ about ] mum — aluminum0.3Ga0.7N by which magnesium was doped by 5x1017/of hole concentration cm 3, and 1x1020/of concentration cm 3 from — p layer 61 and thickness 0.2 [ about ] which change mum — hole concentration 7x1017-/cm3 and magnesium concentration GaN of the magnesium dope of 2x1020-/cm3 from — the contact layer 62 which changes is formed. And the electrode 7 which consists of nickel joined to the contact layer 62 is formed on the contact layer 62. Furthermore, high carrier concentration n+ A part of front face of a layer 3 is exposed, and the electrode 8 which consists of nickel joined to the layer 3 is formed on the outcrop.

[0016] aluminum0.2Ga0.8N of the six-layer barrier layer 51, and thickness about 100 \*\* which consists of aluminum0.25Ga0.75N of thickness about 100 \*\* as the detailed configuration of a luminous layer 5 is shown in drawing 2 from — the five-layer well layer 52 which changes is the multiplex quantum well structure by which the laminating was carried out by turns, and are about 0.11 micrometers of all thickness. Moreover, zinc and silicon are added by the well layer 52 at the concentration of 5x1018-/cm3, respectively.

[0017] Next, the manufacture approach of the light emitting diode 10 of this structure is explained. The above-mentioned light emitting diode 10 is organometallic compound vapor growth (it is described as "MOVPE" below). It was manufactured with the vapor growth to depend. The used gas NH<sub>3</sub>, a silane (SiH<sub>4</sub>), and diethylzinc Carrier gas H<sub>2</sub> or N<sub>2</sub> () Trimethylgallium (Ga<sub>3</sub> (CH<sub>3</sub>)) (it is described as "TMG" below) Trimethylaluminum (aluminum<sub>3</sub> (CH<sub>3</sub>)) (it is described as "TMA" below) It is described as "DEZ" below. It is magnesium cyclopentadienyl (Mg<sub>2</sub> (C<sub>5</sub>H<sub>5</sub>)) (it is described as "CP2Mg" below).

[0018] First, thickness 100—400 which makes a principal plane the a-th page washed by organic washing and heat treatment It is MOVPE about the silicon on sapphire 1 of the single crystal of mum. The susceptor laid in the reaction chamber of equipment is equipped. Next, it was ordinary pressure, and H<sub>2</sub> was carried out by part for rate-of-flow 2 liter/, and gas phase etching of the silicon on sapphire 1 was carried out to the reaction chamber at the temperature of 1100 degrees C with the sink.

[0019] Next, temperature It is made to fall to 400 degrees C, and they are a part for 20 liter/, and NH<sub>3</sub> about H<sub>2</sub>. A part for 10 liter/, and TMA It supplies by part for 1.8x10 —five-mol/, and is AlN. A buffer layer 2 is abbreviation. It was formed in the thickness which is 500A. The temperature of silicon on sapphire 1 is held at 1150 degrees C. H<sub>2</sub> A part for next, 20 liter/, NH<sub>3</sub> A part for 10 liter/, and TMG It is 0.86 ppm by part for 1.7x10—4 RU/, and H<sub>2</sub> gas. The diluted silane is supplied by part for 200ml/for 30 minutes. thickness 2.2 [ about ] mum and concentration of electrons GaN of the silicon dope of 2x1018-/cm3 from — high carrier concentration n+ which changes The layer 3 was formed.

[0020] The temperature of silicon on sapphire 1 is held at 1100 degrees C. N<sub>2</sub> or H<sub>2</sub> A part for next, 10 liter/, NH<sub>3</sub> A part for 10liter/, and TMG 1.12x10 —four-mol a part for /and TMA It is 0.86 ppm by part for 0.47x10 —four-mol/, and H<sub>2</sub> gas. The diluted silane by part for 10x10—9mol/ 60 minutes — supplying — thickness 1 [ about ] aluminum0.3Ga0.7N of mum and the silicon dope of 1x1018/of concentration cm 3 from — n layer 4 which changes was formed.

[0021] then, the temperature of silicon on sapphire 1 — 1100 degrees C — holding — N<sub>2</sub> or H<sub>2</sub> — a part for 20 liter/, and NH<sub>3</sub> A part for 10 liter/, and TMG 1x10 —five-mol a part for /and TMA a part for 0.39x10 —four-mol/— for 3 minutes — introducing — aluminum0.25Ga0.75N from — the barrier layer 51 with a thickness of 100A which changes was formed. Next, they are a part for 20 liter/, and NH<sub>3</sub> about N<sub>2</sub> or H<sub>2</sub>. A part for 10 liter/, and TMG 1x10 —five-mol a part for /and TMA By part for 0.31x10 —four-mol/ And it is 0.86 ppm by H<sub>2</sub> gas. They are a part for 10x10—9mol/, and DEZ about the diluted silane. By part for 2x10 —four-mol/ for 3 minutes — introducing — aluminum0.2Ga0.8N from — silicon with a thickness of 100A which changes, and zinc formed the well layer 52 added by the concentration of 5x1018-/cm3, respectively. By the repeat of such a procedure, as shown in drawing 2 , only the barrier layer 51 and five layers of well layers 52 were \*\*\*\*\*ed by turns, and the luminous layer 5 with a whole thickness of 0.11 micrometers was formed with multiplex quantum well structure.

[0022] Temperature is held at 1100 degrees C. N<sub>2</sub> or H<sub>2</sub> A part for then, 20 liter/, NH<sub>3</sub> A part for 10liter/, and TMG A part for 1.12x10 —four-mol/, TMA A part for /, and 0.47x10 —four-mol CP2Mg a part for 2x10 —four-mol/— for 60 minutes — introducing — thickness 1.0 [ about ] aluminum0.3Ga0.7N of the magnesium (Mg) dope of mum from — p layer 61 which changes was formed. p layers of concentration of the magnesium of 61 are 1x1020-/cm3. In this condition, 61 is still resistivity 108 p layers. It is an insulator more than omegacm.

[0023] Then, temperature was held at 1100 degrees C and the contact layer 62 which consists N<sub>2</sub> or H<sub>2</sub> of a part for 20 liter/and NH<sub>3</sub> was formed. A part for 10liter/, and TMG A part for /, and 1.12x10 —four-mol CP2Mg At 4x10 —four-mol the rate for / It introduces for 4 minutes and is thickness 0.2 [ about ]. GaN of the magnesium (Mg) dope of mum Concentration of the magnesium of the contact layer 62 It is 2x1020-/cm3. In this condition, the contact layer 62 is still resistivity 108. It is an insulator more than omegacm.

[0024] Thus, the wafer of the cross-section structure shown in drawing 2 was obtained. Next, this wafer was heat-treated for 45 minutes at 450 degrees C. By this heat treatment, 61 is hole concentration 62 or p layers of contact layers, respectively. 7x1017-/cm3, 5x1017-/cm3, resistivity 2—ohmcm and 0.8 omegacm It became p conduction type semi-conductor. Thus, the wafer of multilayer structure was obtained.

[0025] next, it is shown in drawing 3 — as — the contact layer 62 top — sputtering — SiO two-layer — 9 was formed in the thickness of 2000A and the photoresist 10 was applied on the SiO two-layer 9. And by photograph RISOGURAFU, as shown in drawing 3 , it sets on the contact layer 62, and it is high carrier concentration n+. Electrode formation part A' to a layer 3 The photoresist 10 was removed. next, the SiO two-layer which is not covered with a photoresist 10 as shown in drawing 4 — the hydrofluoric-acid system etching reagent removed 9.

[0026] Next, 62 or p layer 61 and 5 or n layers of luminous layers of contact layers of the part which is not covered with a photoresist 10 and SiO two-layer 9, after supplying and carrying out dry etching of degree of vacuum 0.04Torr, high-frequency power 0.44 W/cm<sup>2</sup>, and the BCl<sub>3</sub> gas at a rate for 10 ml/, dry etching of 4 was carried out by Ar. As this process shows to drawing 5 , it is high carrier concentration n+. The hole A for electrode drawing to a layer 3 was formed.

[0027] Next, as nickel is vapor-deposited uniformly and it is shown in drawing 1 through spreading of a photoresist, a photolithography process, and an etching process all over the upper [ of a sample ], it is high carrier concentration n+. The electrodes 8 and 7 to a layer 3 and the contact layer 62 were formed. Then, like the above, the processed wafer was cut for each chip and the light emitting diode chip was obtained.

[0028] Thus, the obtained light emitting device is 20mA of drive currents, and is an emission peak wavelength. It was 2mW in 380nm and luminescence reinforcement. This luminous efficiency is 3% and improved by 10 times compared with the thing of the conventional configuration.

[0029] In the above-mentioned example, the band gap of the barrier layer 51 of a luminous layer 5 is formed in a double heterojunction which exists in both sides and which becomes smaller than the band gap of 4 n layers with 61 p layers. Although double heterojunction structure was used in the above-mentioned example, you may be single heterojunction structure. Furthermore, although heat treatment was used for forming p layers, p mold may be formed by electron beam irradiation.

[0030] Although the above-mentioned light emitting diode 10 has added zinc and silicon in each well layer, at coincidence, each well layer 52 and each barrier layer 51 may add acceptor impurity, such as zinc, and donor impurities, such as silicon. Moreover, as shown in drawing 6, the luminous layer 5 of light emitting diode 100 may add silicon and zinc by turns in two or more well layers 520. In this structure, opposite luminescence by acceptor level and donor level is attained, and the luminous efficiency of ultraviolet rays improves. Thus, the obtained light emitting device is 20mA of drive currents, and is an emission peak wavelength. It was 5mW in 380nm and luminescence reinforcement. This luminous efficiency is 7% and improved by 25 times compared with the thing of the conventional configuration.

[0031] Moreover, as shown in drawing 7, what added zinc in all the well layers 521, and added silicon in all the barrier layers 511 is sufficient as a light emitting diode 200. In this structure, opposite luminescence by acceptor level and donor level is attained, and the luminous efficiency of ultraviolet rays improves. In addition, silicon is added in all the well layers 521, and you may make it add zinc in all the barrier layers 511 conversely. Thus, the obtained light emitting device is 20mA of drive currents, and is an emission peak wavelength. It was 5mW in 370nm and luminescence reinforcement. This luminous efficiency is 7% and improved by 25 times compared with the thing of the conventional configuration.

[0032] Furthermore, all the above-mentioned light emitting diodes may be formed into p mold by heat treatment or electron-beam-irradiation processing after adding magnesium, although magnesium is not added by the barrier layer 51,510,511. Thus, the obtained light emitting device is 20mA of drive currents, and is an emission peak wavelength. It was 10mW in 380nm and luminescence reinforcement. This luminous efficiency is 15% and improved by 50 times compared with the thing of the conventional configuration.

[0033] Furthermore, it is good also as a configuration as shows light emitting diode 300 to drawing 8. namely, the light emitting diode 300 — thickness 5.0 [ about ]  $\mu\text{m}$  and concentration Silicon dope GaN of  $5 \times 10^{18}/\text{cm}^3$  from — high carrier concentration  $n^+$  which changes A layer 30 and thickness 0.5 [ about ]  $\mu\text{m}$  — concentration GaN of the silicon dope of  $5 \times 10^{17}/\text{cm}^3$  from — n layers of 40 and the luminous layers 50 of about 0.41 micrometers of all thickness which change, and thickness 0.5 [ about ]  $\mu\text{m}$  —  $5 \times 10^{17}/\text{cm}^3$  hole concentration cm<sup>3</sup>, and concentration aluminum0.08Ga0.92N by which magnesium was doped by  $5 \times 10^{20}/\text{cm}^3$  from — p layer 610 and thickness 1 [ about ] which change  $\mu\text{m}$  — hole concentration  $7 \times 10^{18}/\text{cm}^3$  and magnesium concentration GaN of the magnesium dope of  $5 \times 10^{21}/\text{cm}^3$  from — you may constitute from a contact layer 620 which changes.

[0034] however, the detailed configuration of a luminous layer 50 — GaN of thickness about 100 \*\* from — In0.07Ga0.93N of the 21-layer barrier layer 512, and thickness about 100 \*\* which changes from — the 20-layer well layer 522 which changes is the multiplex quantum well structure by which the laminating was carried out by turns, and are about 0.41 micrometers of all thickness. Moreover, silicon is added by the well layer 522 at the concentration of  $5 \times 10^{18}/\text{cm}^3$ .

[0035] Thus, the obtained light emitting device was 20mA of drive currents, and was 2mW in 380nm of emission peak wavelengths, and luminescence reinforcement. This luminous efficiency is 3% and improved by 10 times compared with the thing of the conventional configuration.

[0036] in addition, the well layer 522 of a luminous layer 50 — In0.07Ga0.93N although used — aluminum0.03Ga0.89In0.08N etc. — 3 group nitride semi-conductor of a system of 4 yuan may be used. Moreover, it is GaN to the barrier layer 512. Alx2GaY2In1-X2-Y2N which has bigger forbidden-band width of face than the forbidden-band width of face of the well layer 522 although used A semi-conductor may be used. Moreover, the repeat number of layers of the multiplex quantum well of a luminous layer 50 can use one to about 20. Furthermore, the barrier layer 512 and the well layer 522 are good to choose a presentation ratio so that an abbreviation lattice constant may be made in agreement.

[0037] Moreover, the luminous layer of all the above-mentioned light emitting diodes is In0.07Ga0.93N of about 0.5 micrometers of thickness about a luminous layer 501, as it is shown in drawing 9 as other light emitting diodes 400, although considered as multiplex quantum well structure. You may constitute. The light emitting diode in this case was 20mA of drive currents, and was 1mW in emission-peak-wavelength 380 nm and luminescence reinforcement. This luminous efficiency is 1.5% and improved by 5 times compared with the thing of the conventional configuration. Although this luminous layer 501 has not added the impurity, acceptor impurity, such as donor impurities, such as silicon, and zinc, may be added. A luminous layer 501 is thickness 0.5. Luminous efficiency is not reduced, even if it becomes thick and the obstruction between 40 and a luminous layer 501 is smaller than the diffusion length of an electron hole n layers, since it is made  $\mu\text{m}$ .

[0038] Moreover, the light emitting diode shown in drawing 8 and drawing 9 is  $n^+$ . With n layers of layers 30, since 40 is [ both ] GaN, the grid mismatching between these layers does not exist. Therefore, the misfit rearrangement by this grid mismatching does not occur in a luminous layer 50,501. Moreover, GaN In0.07Ga0.93N The grid mismatching of a between is small and the misfit rearrangement of the luminous layer 50,501 accompanying the grid mismatching of 40 and a luminous layer 50 is n layers fewer than. Therefore, the crystallinity of a luminous layer became good.

[0039] Although double heterojunction structure was used in the above-mentioned example, you may be single heterojunction structure. Furthermore, although heat treatment was used for forming p layers, p mold may be formed by electron beam irradiation. Although the example of light emitting diode was shown, even if it is a laser diode, it can constitute similarly.

[0040] Thus, as shown in drawing 10 (light emitting diode is represented and is shown by 10 by a diagram), after being attached in the flat part 203 of the upper part of lead 201, connecting lead 201 with an electrode 8 with a wire 204 and connecting lead 202 with an electrode 7 with a wire 205, in order to form a lens 206, resin shaping of the formed light emitting diode 10,100,200,300,400 is carried out. Fluorescent paint is applied to the top face of this lens 206, and the fluorescent substance layer 207 is formed. The fluorescent material of a fluorescent pigment, fluorescent dye, and others can be used for the fluorescent substance layer 207. The luminescent color of arbitration can be obtained because only the matter of the fluorescent substance layer 207 changes this fluorescent substance layer 207, without changing the color of arbitration, for example, red, green, blue, then the quality of the material and structure of light emitting diode. as a fluorescent substance — Zn0.2Cd0.8 S:Ag, Zn0.6Cd0.4 S:Ag, and 10(Sr, calcium) (PO<sub>4</sub>)<sub>6</sub>CL<sub>2</sub>:Eu etc. — it can use. Moreover, they are ZnS:Cu and aluminum as a fluorescent substance of green luminescence. A fluorescent substance and Y<sub>2</sub>aluminum5O<sub>12</sub>:Tb It is Y<sub>2</sub>O<sub>3</sub>:Eu as a mixture with a fluorescent substance, and a fluorescent substance of red luminescence. They are ZnS:Ag and aluminum as the mixture of a fluorescent substance and a Y<sub>2</sub>O<sub>3</sub> S:Eu fluorescent substance, and a fluorescent substance of blue luminescence. A fluorescent substance can also be used.

[0041] Moreover, as shown in drawing 11, the fluorescent substance layer 208 may be formed on the electrode 7 which is the maximum upper layer of light emitting diode 500. Furthermore, as shown in drawing 12, in the case of the light emitting diode 600 of a flip chip mold, the fluorescent substance layer 209 may be formed on field 1a of the side in which the luminous layer 5 of silicon on sapphire 1 is not formed. Furthermore, as shown in drawing 13, the fluorescent substance layer 210 which carries out incidence of the ultraviolet rays from a luminous layer 701 may be formed in the side face of light emitting diode 700.

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DESCRIPTION OF DRAWINGS

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## [Brief Description of the Drawings]

[Drawing 1] The block diagram having shown the configuration of the light emitting diode used for the light emitting device concerning the concrete example of this invention.

[Drawing 2] The sectional view having shown the production process of the light emitting diode of this example.

[Drawing 3] The sectional view having shown the production process of the light emitting diode of this example.

[Drawing 4] The sectional view having shown the production process of the light emitting diode of this example.

[Drawing 5] The sectional view having shown the production process of the light emitting diode of this example.

[Drawing 6] The block diagram having shown the configuration of the light emitting diode of other examples.

[Drawing 7] The block diagram having shown the configuration of the light emitting diode of other examples.

[Drawing 8] The block diagram having shown the configuration of the light emitting diode of other examples.

[Drawing 9] The block diagram having shown the configuration of the light emitting diode of other examples.

[Drawing 10] The block diagram having shown the configuration of a light emitting device with light emitting diode.

[Drawing 11] The block diagram having shown other configurations of a light emitting device.

[Drawing 12] The block diagram having shown other configurations of a light emitting device.

[Drawing 13] The block diagram having shown other configurations of a light emitting device.

## [Description of Notations]

10, 100, 200, 300, 400, 500, 600, 700 — Light emitting diode

1 — Silicon on sapphire

2 — Buffer layer

3 30 — Quantity carrier concentration n+ Layer

4 40—n layers

5 50,501,701 — Luminous layer

51,510,511,512 — Barrier layer

52,520,521,522 — Well layer

61,610—p layers

62,620 — Contact layer

7 8 — Electrode

207,208,209,210 — Fluorescent substance layer

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[Translation done.]

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(71)出願人 000241463

豊田合成株式会社

愛知県西春日井郡春日町大字落合字長畑1  
番地

(71)出願人 591014949

赤崎 勇

愛知県名古屋市西区浄心1丁目1番38-805

(71)出願人 591014950

天野 浩

愛知県名古屋市名東区山の手2丁目104 宝  
マンション山の手508号

(74)代理人 弁理士 藤谷 修

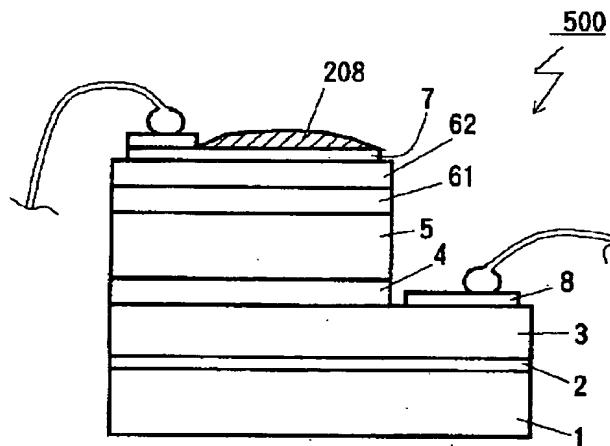
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(54)【発明の名称】3族窒化物半導体発光素子

(57)【要約】

【課題】高輝度の青色から緑色の発光を得ると共に3族窒化物半導体だけで、各種の色の発光を得るようにすること。

【解決手段】発光ダイオード500はサファイア基板1、バッファ層2、高キャリア濃度n<sup>+</sup>層3、SiドープのAl<sub>0.3</sub>Ga<sub>0.7</sub>Nから成るn層4、発光層5、MgドープのAl<sub>0.3</sub>Ga<sub>0.7</sub>Nから成るp層61、MgドープのGaNから成るコンタクト層62、Niから成る電極7、電極8で構成されている。発光層5は、膜厚約100 ÅのAl<sub>0.25</sub>Ga<sub>0.75</sub>Nから成る6層のバリア層51と膜厚約100 ÅのAl<sub>0.2</sub>Ga<sub>0.8</sub>Nから成る5層の井戸層52とが交互に積層された多重量子井戸構造である。井戸層52には、亜鉛とシリコンが、それぞれ、5×10<sup>18</sup>/cm<sup>3</sup>の濃度に添加されている。このような紫外線を発光する発光層5と、発光層5の放射する紫外線を受光して、電極7の上に可視光に変換する蛍光体層208とを設けた。



## 【特許請求の範囲】

【請求項 1】発光層に 3 族窒化物半導体を用いた発光素子において、

紫外線を発光する発光層と、

前記発光層の放射する前記紫外線を受光して、可視光に変換する蛍光体層とを設けたことを特徴とする発光素子。

【請求項 2】前記蛍光体層は光を外部に放射するためのレンズ体に形成されていることを特徴とする請求項 1 に記載の発光素子。

【請求項 3】前記発光層に給電するための電極層を有し、前記蛍光体層はその電極層上に形成されていることを特徴とする請求項 1 に記載の発光素子。

【請求項 4】前記発光層を形成するためのサファイア基板を有し、前記蛍光体層はそのサファイア基板の前記発光層の形成側とは反対側の面に形成されていることを特徴とする請求項 1 に記載の発光素子。

【請求項 5】前記蛍光体層は、前記発光層の側面に形成されていることを特徴とする請求項 1 に記載の発光素子。

【請求項 6】前記発光層は、 $Al_{x_1}Ga_{y_1}In_{1-x_1-y_1}N$ から成る井戸層とこの井戸層よりも禁制帯幅の広い $Al_{x_2}Ga_{y_2}In_{1-x_2-y_2}N$ から成るバリア層とを少なくとも 1 層以上交互に積層させた量子井戸で構成され、前記発光層にアクセプタ不純物とドナー不純物とを添加したことを特徴とする請求項 1 に記載の発光素子。

【請求項 7】前記発光層の各井戸層、又は、各井戸層及び各バリア層に前記アクセプタ不純物と前記ドナー不純物とが共に添加されていることを特徴とする請求項 6 に記載の発光素子。

【請求項 8】前記発光層の隣接する井戸層に、前記アクセプタ不純物と前記ドナー不純物とが交互に添加されていることを特徴とする請求項 6 に記載の発光素子。

【請求項 9】前記発光層の前記井戸層には前記アクセプタ不純物が、前記発光層の前記バリア層には前記ドナー不純物が、逆に、前記井戸層には前記ドナー不純物が、前記バリア層には前記アクセプタ不純物が、それぞれ、添加されていることを特徴とする請求項 6 に記載の発光素子。

【請求項 10】前記バリア層は $GaN$ から成ることを特徴とする請求項 6 に記載の発光素子。

【請求項 11】前記井戸層と前記バリア層は格子定数が一致していることを特徴とする請求項 6 に記載の発光素子。

【請求項 12】前記発光層は、p 伝導型の p 層と n 伝導型の n 層とで挟まれ、正孔の拡散長よりも厚く構成し、前記 n 層を、前記発光層と格子定数が略等しくなるドナー不純物が添加された $Al_{x_3}Ga_{y_3}In_{1-x_3-y_3}N$  半導体で構成し、

前記 p 層を、前記発光層に注入された電子を閉じ込める

のに十分なだけ、前記発光層よりも禁制帯幅が大きいアクセプタ不純物が添加された $Al_{x_4}Ga_{y_4}In_{1-x_4-y_4}N$  半導体で構成したことを特徴とする請求項 1 に記載の発光素子。

【請求項 13】前記発光層は $Ga_{y_5}In_{1-y_5}N$  ( $0.92 \leq y_5 \leq 1$ ) で構成され、前記 n 層はドナー不純物が添加された $GaN$  で構成されていることを特徴とする請求項 1 に記載の発光素子。

## 【発明の詳細な説明】

10 【0001】

【発明の属する技術分野】本発明は発光色を任意に設定できる 3 族窒化物半導体を用いた半導体発光素子に関する。

【0002】

【従来技術】従来、青色発光の得られる $InGaN$  を用いた半導体発光素子が知られている。さらに、この発光素子でより長波長の緑色発光を得るために、発光層の禁制帯幅を狭くするために In の組成比を大きくすることが行われている。

20 【0003】

【発明が解決しようとする課題】しかし、In の組成比を大きくすると、発光層の結晶性が悪化し発光効率が低下する。従って、発光波長を長くするに連れて発光輝度が低くなり、未だ、高輝度の青色から緑色の発光が得られていない。又、各種の発光色を得る場合には、その発光色の波長に相当した禁制帯幅の半導体材料が用いられていた。

30 【0004】本発明は上記の課題を解決するために成されたものであり、その目的は、高輝度の青色から緑色の発光を得ると共に、3 族窒化物半導体だけで、各種の色の発光を得るようにすることである。

【0005】

【課題を解決するための手段】請求項 1 の発明によれば、紫外線を発光する 3 族窒化物半導体を用いた発光層と、その発光層の放射する紫外線を受光して、可視光に変換する蛍光体層とを設けたものである。よって、蛍光体は可視光よりも短い波長の紫外線により励起されるため、蛍光体の材質を変化させるだけで、各種の色の可視光を得ることができる。

40 【0006】請求項 2 の発明はレンズ体に形成された蛍光体層、請求項 3 の発明は電極層上に形成された蛍光体層、請求項 4 の発明は透明なサファイア基板面に形成された蛍光体層、請求項 5 の発明は発光層の側面に形成された蛍光体層により、発光層からの紫外線が可視光に変換される。いずれも、蛍光体層の蛍光体の種類を変化させるだけで、発光色を変化させることができる。

50 【0007】請求項 6 ~ 13 は、紫外線を放射する発光層に関するものである。請求項 6 ~ 11 の発明では、発光層を $AlGaN$  の少なくとも 1 層以上積層させた量子井戸構造とし、発光層にドナー不純物又はアクセプタ不純

3

物を添加した。このため、ドナー準位、又は、アクセプタ準位が形成されるため、発光に寄与する電子とホールの再結合確率が増大するため、再結合による発光効率が向上する。又、インジウムの組成比と不純物濃度は、希望する発光ピーク波長と発光強度との関係で決定される。

【0008】特に、発光層にInGaN よりも結晶性の良いAlGaN を用い、発光層を量子井戸構造の歪超格子として、格子定数のミスマッチの伝搬を防止して井戸層の結晶性を向上させ、これにより発光効率を向上させることができた。特に、結晶性の良い井戸層にアクセプタ不純物とドナー不純物と共に添加して、アクセプタ準位とドナー準位による対発光により、紫外線の発光効率を大きく向上させることができた。

【0009】尚、発光層のAlのモル組成比は15%以上とし、井戸層の厚さは50Å～200Åの範囲が望ましい。50Å以下だと不純物拡散が起こり、200Å以上だと量子効果が発生しなくなるので望ましくない。又、バリア層の厚さは50Å～200Åの範囲が望ましい。50Å以下だと井戸層にキャリアを閉じ込める効率が下がるため望ましくなく、200Å以上だと量子効果が発生しなくなるので望ましくない。200Å以上だとノンドープの場合には抵抗が大きくなり、又、ドープした場合には転位によるクラックが入るので望ましくない。

【0010】又、発光層に添加するアクセプタ不純物とドナー不純物の濃度は $1 \times 10^{17}/\text{cm}^3 \sim 1 \times 10^{20}/\text{cm}^3$  の範囲が望ましい。 $1 \times 10^{17}/\text{cm}^3$  以下であると、発光中心不足により発光効率が低下し、 $1 \times 10^{20}/\text{cm}^3$  以上となると、結晶性が悪くなり、又、オージェ効果が発生するので望ましくない。

【0011】又、請求項12の発明では、n層は発光層と格子定数が略等しくなるように、 $\text{Al}_{x_3}\text{Ga}_{y_3}\text{In}_{1-x_3-y_3}\text{N}$  の組成比 $x_3, y_3$  が決定され、p層は発光層に対してn層から注入された電子を十分に閉じ込めるだけ、禁制帯幅が大きくなるように、 $\text{Al}_{x_4}\text{Ga}_{y_4}\text{In}_{1-x_4-y_4}\text{N}$  の組成比 $x_4, y_4$  が決定される。このようにn層を決定することで、n層と発光層との格子定数の相違によるミスマッチが少なく、発光層の結晶性が向上する。

【0012】n層と発光層との接合による障壁は、p層から発光層に注入された正孔を閉じ込める作用をする。ところが、正孔の拡散長は数1000Åであり、発光層はその拡散長よりも厚く構成されている。よって、n層と発光層との接合による障壁は、正孔の発光層内での閉じ込めに有効に寄与しない。したがって、n層と発光層間の障壁は小さくても良いので、n層は発光層に対して格子定数が略等しくなるように、 $\text{Al}_{x_3}\text{Ga}_{y_3}\text{In}_{1-x_3-y_3}\text{N}$  の組成比 $x_3, y_3$  を決定することで、n層と発光層との間の格子不整合を極力小さくすることができ、発光層の結晶性を向上させることが可能となる。この結果、紫外線の発光効率が向上する。

【0013】紫外線を発光するために、発光層を $\text{Ga}_{y_5}\text{In}_{1-y_5}\text{N}$ ( $0.92 \leq y_5 \leq 1$ )で構成した場合には、n層をGaN とすることで、格子不整合を小さくすることができる。

【0014】又、上記の発光ダイオードはサファイア基板上に、バッファ層を形成し、その上にn層に対する電流のリードとして機能する高濃度にシリコンが添加されたGaN から成るn<sup>+</sup> 層を形成することもできる。この場合には、n層をGaN で構成することで、n<sup>+</sup> 層とn層との格子定数は完全に一致し、ミスマッチ転位は発生しない。よって、発光層の結晶性がより向上する。

【0015】

【発明の実施の形態】紫外線を発光する発光ダイオードの構造について説明する。図1において、発光ダイオード10は、サファイア基板1を有しており、そのサファイア基板1上に500ÅのAlNのバッファ層2が形成されている。そのバッファ層2の上には、順に、膜厚約2.0μm、電子濃度 $2 \times 10^{18}/\text{cm}^3$ のシリコンドープGaNから成る高キャリア濃度n<sup>+</sup>層3、膜厚約1.0μm、電子濃度 $2 \times 10^{18}/\text{cm}^3$ のシリコンドープの $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$ から成るn層4、全膜厚約0.11μmの発光層5、膜厚約1.0μm、ホール濃度 $5 \times 10^{17}/\text{cm}^3$ 、濃度 $1 \times 10^{20}/\text{cm}^3$ にマグネシウムがドープされた $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$ から成るp層61、膜厚約0.2μm、ホール濃度 $7 \times 10^{17}/\text{cm}^3$ 、マグネシウム濃度 $2 \times 10^{20}/\text{cm}^3$ のマグネシウムドープのGaNから成るコンタクト層62が形成されている。そして、コンタクト層62上にコンタクト層62に接合するNiから成る電極7が形成されている。さらに、高キャリア濃度n<sup>+</sup>層3の表面の一部は露出しており、その露出部上にその層3に接合するNiから成る電極8が形成されている。

【0016】発光層5の詳細な構成は、図2に示すように、膜厚約100Åの $\text{Al}_{0.26}\text{Ga}_{0.75}\text{N}$ から成る6層のバリア層51と膜厚約100Åの $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ から成る5層の井戸層52とが交互に積層された多重量子井戸構造で、全膜厚約0.11μmである。又、井戸層52には、亜鉛とシリコンが、それぞれ、 $5 \times 10^{18}/\text{cm}^3$ の濃度に添加されている。

【0017】次に、この構造の発光ダイオード10の製造方法について説明する。上記発光ダイオード10は、40 有機金属化合物気相成長法(以下「MOVPE」と記す)による気相成長により製造された。用いられたガスは、NH<sub>3</sub>とキャリアガスH<sub>2</sub>又はN<sub>2</sub>とトリメチルガリウム(Ga(CH<sub>3</sub>)<sub>3</sub>) (以下「TMG」と記す)とトリメチルアルミニウム(Al(CH<sub>3</sub>)<sub>3</sub>) (以下「TMA」と記す)とシラン(SiH<sub>4</sub>)とジエチル亜鉛(以下「DEZ」と記す)とシクロペンタジエニルマグネシウム(Mg(C<sub>5</sub>H<sub>5</sub>)<sub>2</sub>) (以下「CP<sub>2</sub>Mg」と記す)である。

【0018】まず、有機洗浄及び熱処理により洗浄したa面を主面とする厚さ100～400μmの単結晶のサファイア基板1をMOVPE装置の反応室に載置されたサセプタ

に装着する。次に、常圧でH<sub>2</sub>を流速2.liter/分で反応室に流しながら温度1100°Cでサファイア基板1を気相エッチングした。

【0019】次に、温度を400°Cまで低下させて、H<sub>2</sub>を20 liter/分、NH<sub>3</sub>を10 liter/分、TMAを $1.8 \times 10^{-5}$ モル/分で供給してAlNのバッファ層2が約500Åの厚さに形成された。次に、サファイア基板1の温度を1150°Cに保持し、H<sub>2</sub>を20 liter/分、NH<sub>3</sub>を10 liter/分、TMGを $1.7 \times 10^{-4}$ ル/分、H<sub>2</sub>ガスにより0.86ppmに希釈されたシランを200ml/分で30分供給して、膜厚約2.2μm、電子濃度 $2 \times 10^{18}/\text{cm}^3$ のシリコンドープのGaNから成る高キャリア濃度n<sup>+</sup>層3を形成した。

【0020】次に、サファイア基板1の温度を1100°Cに保持し、N<sub>2</sub>又はH<sub>2</sub>を10 liter/分、NH<sub>3</sub>を10liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、TMAを $0.47 \times 10^{-4}$ モル/分、及び、H<sub>2</sub>ガスにより0.86ppmに希釈されたシランを $10 \times 10^{-9}\text{mol}/\text{分}$ で、60分供給して、膜厚約1μm、濃度 $1 \times 10^{18}/\text{cm}^3$ のシリコンドープのAl<sub>0.3</sub>Ga<sub>0.7</sub>Nから成るn層4を形成した。

【0021】その後、サファイア基板1の温度を1100°Cに保持し、N<sub>2</sub>又はH<sub>2</sub>を20 liter/分、NH<sub>3</sub>を10 liter/分、TMGを $1 \times 10^{-5}$ モル/分、TMAを $0.39 \times 10^{-4}$ モル/分で3分間導入してAl<sub>0.25</sub>Ga<sub>0.75</sub>Nから成る厚さ100Åのバリア層51を形成した。次に、N<sub>2</sub>又はH<sub>2</sub>を20 liter/分、NH<sub>3</sub>を10 liter/分、TMGを $1 \times 10^{-5}$ モル/分、TMAを $0.31 \times 10^{-4}$ モル/分で、且つ、H<sub>2</sub>ガスにより0.86ppmに希釈されたシランを $10 \times 10^{-9}\text{mol}/\text{分}$ 、DEZを $2 \times 10^{-4}$ モル/分で、3分間導入してAl<sub>0.2</sub>Ga<sub>0.8</sub>Nから成る厚さ100Åのシリコンと亜鉛が、それぞれ、 $5 \times 10^{18}/\text{cm}^3$ の濃度に添加された井戸層52を形成した。このような手順の繰り返しにより、図2に示すように、バリア層51と井戸層52とを交互に5層だけ積層した多重量子井戸構造で、全体の厚さ0.11μmの発光層5を形成した。

【0022】続いて、温度を1100°Cに保持し、N<sub>2</sub>又はH<sub>2</sub>を20 liter/分、NH<sub>3</sub>を10liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、TMAを $0.47 \times 10^{-4}$ モル/分、及び、CP<sub>2</sub>Mgを $2 \times 10^{-4}$ モル/分で60分間導入し、膜厚約1.0μmのマグネシウム(Mg)ドープのAl<sub>0.3</sub>Ga<sub>0.7</sub>Nから成るp層61を形成した。p層61のマグネシウムの濃度は $1 \times 10^{20}/\text{cm}^3$ である。この状態では、p層61は、まだ、抵抗率 $10^8 \Omega\text{cm}$ 以上の絶縁体である。

【0023】続いて、温度を1100°Cに保持し、N<sub>2</sub>又はH<sub>2</sub>を20 liter/分、NH<sub>3</sub>を10liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、及び、CP<sub>2</sub>Mgを $4 \times 10^{-4}$ モル/分の割合で4分間導入し、膜厚約0.2μmのマグネシウム(Mg)ドープのGaNから成るコンタクト層62を形成した。コンタクト層62のマグネシウムの濃度は $2 \times 10^{20}/\text{cm}^3$ である。この状態では、コンタクト層62は、まだ、抵抗率 $10^8 \Omega\text{cm}$ 以上の絶縁体である。

【0024】このようにして、図2に示す断面構造のウエハが得られた。次に、このウエハを、450°Cで45分間、熱処理した。この熱処理により、コンタクト層62、p層61は、それぞれ、ホール濃度 $7 \times 10^{17}/\text{cm}^3$ 、 $5 \times 10^{17}/\text{cm}^3$ 、抵抗率 $2 \Omega\text{cm}$ 、 $0.8 \Omega\text{cm}$ のp伝導型半導体となった。このようにして、多層構造のウエハが得られた。

【0025】次に、図3に示すように、コンタクト層62の上に、スパッタリングによりSiO<sub>2</sub>層9を2000Åの厚さに形成し、そのSiO<sub>2</sub>層9上にフォトレジスト10を塗布した。そして、フォトリソグラフにより、図3に示すように、コンタクト層62上において、高キャリア濃度n<sup>+</sup>層3に対する電極形成部位A'のフォトレジスト10を除去した。次に、図4に示すように、フォトレジスト10によって覆われていないSiO<sub>2</sub>層9をフッ化水素酸系エッティング液で除去した。

【0026】次に、フォトレジスト10及びSiO<sub>2</sub>層9によって覆われていない部位のコンタクト層62、p層61、発光層5、n層4を、真空間0.04Torr、高周波電力0.44W/cm<sup>2</sup>、BCl<sub>3</sub>ガスを10 ml/分の割合で供給しドライエッティングした後、Arでドライエッティングした。この工程で、図5に示すように、高キャリア濃度n<sup>+</sup>層3に対する電極取出しのための孔Aが形成された。

【0027】次に、試料の上全面に、一様にNiを蒸着し、フォトレジストの塗布、フォトリソグラフィ工程、エッティング工程を経て、図1に示すように、高キャリア濃度n<sup>+</sup>層3及びコンタクト層62に対する電極8、7を形成した。その後、上記の如く処理されたウエハを各チップに切断して、発光ダイオードチップを得た。

【0028】このようにして得られた発光素子は、駆動電流20mAで、発光ピーク波長380nm、発光強度2mWであった。この発光効率は3%であり、従来の構成のものに比べて10倍に向上した。

【0029】上記の実施例では、発光層5のバリア層51のバンドギャップが両側に存在するp層61とn層4のバンドギャップよりも小さくなるようなダブルヘテロ接合に形成されている。上記実施例ではダブルヘテロ接合構造を用いたが、シングルヘテロ接合構造であっても良い。さらに、p層を形成するのに熱処理を用いたが、電子線照射によってp型化しても良い。

【0030】上記の発光ダイオード10は、各井戸層52に亜鉛とシリコンとを同時に添加しているが、各井戸層52と各バリア層51共に亜鉛等のアクセプタ不純物とシリコン等のドナー不純物とを添加しても良い。又、図6に示すように、発光ダイオード100の発光層5は、複数の井戸層520に、順に交互に、シリコンと亜鉛を添加しても良い。この構造において、アクセプタ準位とドナー準位による対発光が可能となり、紫外線の発光効率が向上する。このようにして得られた発光素子は、駆動電流20mAで、発光ピーク波長380nm、発光強度

5mWであった。この発光効率は7%であり、従来の構成のものに比べて25倍に向上了した。

【0031】又、図7に示すように、発光ダイオード200は、全ての井戸層521に亜鉛を添加し、全てのバリア層511にシリコンを添加したものでも良い。この構造において、アクセプタ準位とドナー準位による対発光が可能となり、紫外線の発光効率が向上する。尚、逆に、全ての井戸層521にシリコンを添加し、全てのバリア層511に亜鉛を添加するようにしても良い。このようにして得られた発光素子は、駆動電流20mAで、発光ピーク波長370nm、発光強度5mWであった。この発光効率は7%であり、従来の構成のものに比べて25倍に向上了した。

【0032】さらに、上記の全ての発光ダイオードは、バリア層51、510、511にはマグネシウムが添加されていないが、マグネシウムを添加した後の、熱処理、又は、電子線照射処理によりp型化しても良い。このようにして得られた発光素子は、駆動電流20mAで、発光ピーク波長380nm、発光強度10mWであった。この発光効率は15%であり、従来の構成のものに比べて50倍に向上了した。

【0033】さらに、発光ダイオード300を図8に示すような構成としても良い。即ち、発光ダイオード300を膜厚約5.0μm、濃度 $5 \times 10^{18}/\text{cm}^3$ のシリコンドープGaNから成る高キャリア濃度n<sup>+</sup>層30、膜厚約0.5μm、濃度 $5 \times 10^{17}/\text{cm}^3$ のシリコンドープのGaNから成るn層40、全膜厚約0.41μmの発光層50、膜厚約0.5μm、ホール濃度 $5 \times 10^{17}/\text{cm}^3$ 、濃度 $5 \times 10^{20}/\text{cm}^3$ にマグネシウムがドープされたAl<sub>0.08</sub>Ga<sub>0.92</sub>Nから成るp層610、膜厚約1μm、ホール濃度 $7 \times 10^{18}/\text{cm}^3$ 、マグネシウム濃度 $5 \times 10^{21}/\text{cm}^3$ のマグネシウムドープのGaNから成るコンタクト層620で構成しても良い。

【0034】但し、発光層50の詳細な構成は、膜厚約100ÅのGaNから成る21層のバリア層512と膜厚約100ÅのIn<sub>0.07</sub>Ga<sub>0.93</sub>Nから成る20層の井戸層522とが交互に積層された多重量子井戸構造で、全膜厚約0.41μmである。又、井戸層522には、シリコンが $5 \times 10^{18}/\text{cm}^3$ の濃度に添加されている。

【0035】このようにして得られた発光素子は、駆動電流20mAで、発光ピーク波長380nm、発光強度2mWであった。この発光効率は3%であり、従来の構成のものに比べて10倍に向上了した。

【0036】尚、発光層50の井戸層522にIn<sub>0.07</sub>Ga<sub>0.93</sub>Nを用いたが、Al<sub>0.03</sub>Ga<sub>0.97</sub>In<sub>0.08</sub>N等の4元系の3族窒化物半導体を用いてもよい。又、バリア層512にGaNを用いたが、井戸層522の禁制帯幅よりも大きな禁制帯幅を有するAl<sub>x2</sub>Ga<sub>y2</sub>In<sub>1-x2-y2</sub>N半導体を用いても良い。又、発光層50の多重量子井戸の繰り返し層数は1~20程度を用いることができる。さらに、バリア層512と井戸層522は略格子定数を一致させるよ

うに組成比を選択するのが良い。

【0037】又、上記の全ての発光ダイオードの発光層は多重量子井戸構造としたが、他の発光ダイオード400として、図9に示すように、発光層501を、膜厚約0.5μmのIn<sub>0.07</sub>Ga<sub>0.93</sub>Nで構成しても良い。この場合の発光ダイオードは、駆動電流20mAで、発光ピーク波長380nm、発光強度1mWであった。この発光効率は1.5%であり、従来の構成のものに比べて5倍に向上了した。この発光層501は不純物を添加していないが、シリコン等のドナー不純物や亜鉛等のアクセプタ不純物を添加しても良い。発光層501は厚さ0.5μmにしているので、正孔の拡散長よりも厚くなり、n層40と発光層501との間の障壁が小さくても、発光効率を低下させることはない。

【0038】又、図8と図9に示す発光ダイオードは、n<sup>+</sup>層30とn層40とは共にGaNであるので、これらの層間での格子不整合は存在しない。よって、この格子不整合によるミスフィット転位が発光層50、501に発生することはない。又、GaNとIn<sub>0.07</sub>Ga<sub>0.93</sub>Nとの間の格子不整合は小さく、n層40と発光層50との格子不整合に伴う発光層50、501のミスフィット転位は少ない。よって、発光層の結晶性が良くなつた。

【0039】上記実施例ではダブルヘテロ接合構造を用いたが、シングルヘテロ接合構造であっても良い。さらに、p層を形成するのに熱処理を用いたが、電子線照射によってp型化しても良い。発光ダイオードの例を示したが、レーザダイオードであっても同様に構成可能である。

【0040】このようにして形成された発光ダイオード100、1000、2000、3000、4000は、図10に示すように（図では発光ダイオードは代表して10で示されている）、リード201の上部の平坦部203に取り付けられ、電極8とリード201がワイヤ204で接続され、電極7とリード202がワイヤ205で接続された後、レンズ206を形成するために樹脂成形される。このレンズ206の上面に蛍光塗料が塗布されて、蛍光体層207が形成されている。蛍光体層207には蛍光顔料、蛍光染料、その他の蛍光物質を用いることができる。この蛍光体層207を任意の色、例えば、赤、緑、青とすれば、発光ダイオードの材質や構造を変化させることなく、蛍光体層207の物質だけ変化させることで、任意の発光色を得ることができる。蛍光体としては、Zn<sub>0.2</sub>Cd<sub>0.8</sub>S:Ag、Zn<sub>0.6</sub>Cd<sub>0.4</sub>S:Ag、(Sr,Ca)<sub>10</sub>(PO<sub>4</sub>)<sub>6</sub>Cl<sub>2</sub>:Eu等を用いることができる。又、緑色発光の蛍光体としてZnS:Cu,Al 蛍光体とY<sub>2</sub>Al<sub>5</sub>O<sub>12</sub>:Tb 蛍光体との混合体、赤色発光の蛍光体としてY<sub>2</sub>O<sub>3</sub>:Eu 蛍光体とY<sub>2</sub>O<sub>3</sub>S:Eu 蛍光体との混合体、青色発光の蛍光体としてZnS:Ag,A<sub>1</sub> 蛍光体を用いることもできる。

【0041】又、図11に示すように、発光ダイオード500の最上層である電極7の上に蛍光体層208を形

成しても良い。さらに、図1,2に示すように、フリップチップ型の発光ダイオード600の場合には、サファイア基板1の発光層5が形成されていない側の面1a上に蛍光体層209を形成しても良い。さらに、図1,3に示すように、発光ダイオード700の側面に発光層701からの紫外線を入射する蛍光体層210を形成して良い。

【図面の簡単な説明】

【図1】本発明の具体的な実施例にかかる発光素子用いられる発光ダイオードの構成を示した構成図。

【図2】同実施例の発光ダイオードの製造工程を示した断面図。

【図3】同実施例の発光ダイオードの製造工程を示した断面図。

【図4】同実施例の発光ダイオードの製造工程を示した断面図。

【図5】同実施例の発光ダイオードの製造工程を示した断面図。

【図6】他の例の発光ダイオードの構成を示した構成図。

【図7】他の例の発光ダイオードの構成を示した構成図。

【図8】他の例の発光ダイオードの構成を示した構成

図。

【図9】他の例の発光ダイオードの構成を示した構成図。

【図10】発光ダイオードを有した発光素子の構成を示した構成図。

【図11】発光素子の他の構成を示した構成図。

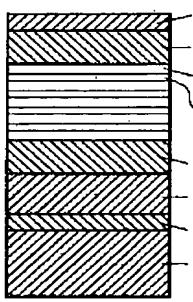
【図12】発光素子の他の構成を示した構成図。

【図13】発光素子の他の構成を示した構成図。

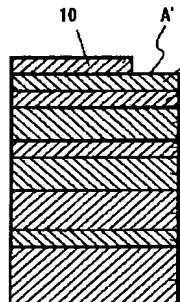
【符号の説明】

- 10 10, 100, 200, 300, 400, 500, 600  
0, 700…発光ダイオード  
1…サファイア基板  
2…バッファ層  
3, 30…高キャリア濃度n<sup>+</sup>層  
4, 40…n層  
5, 50, 501, 701…発光層  
51, 510, 511, 512…バリア層  
52, 520, 521, 522…井戸層  
61, 610…p層  
20 62, 620…コンタクト層  
7, 8…電極  
207, 208, 209, 210…蛍光体層

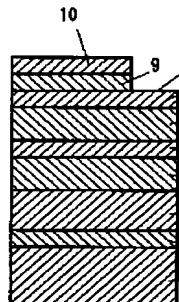
【図2】



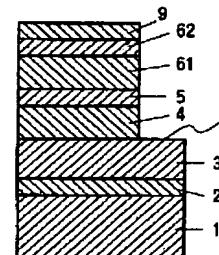
【図3】



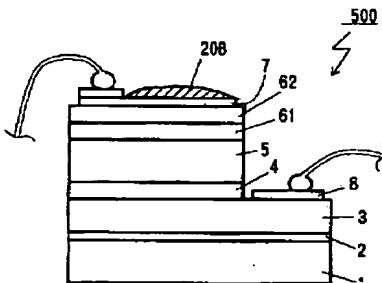
【図4】



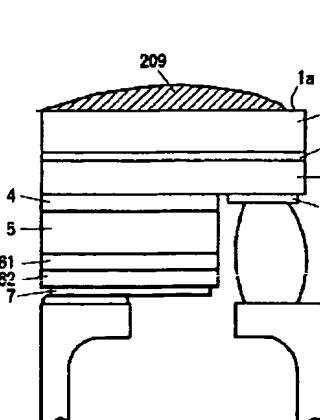
【図5】



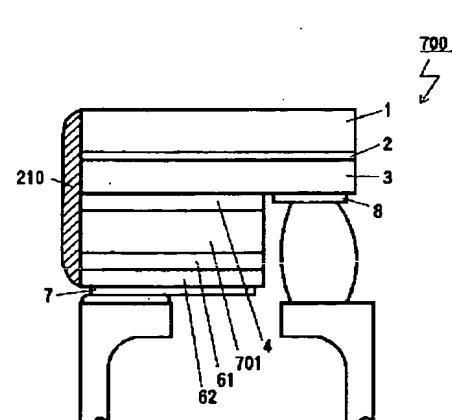
【図11】



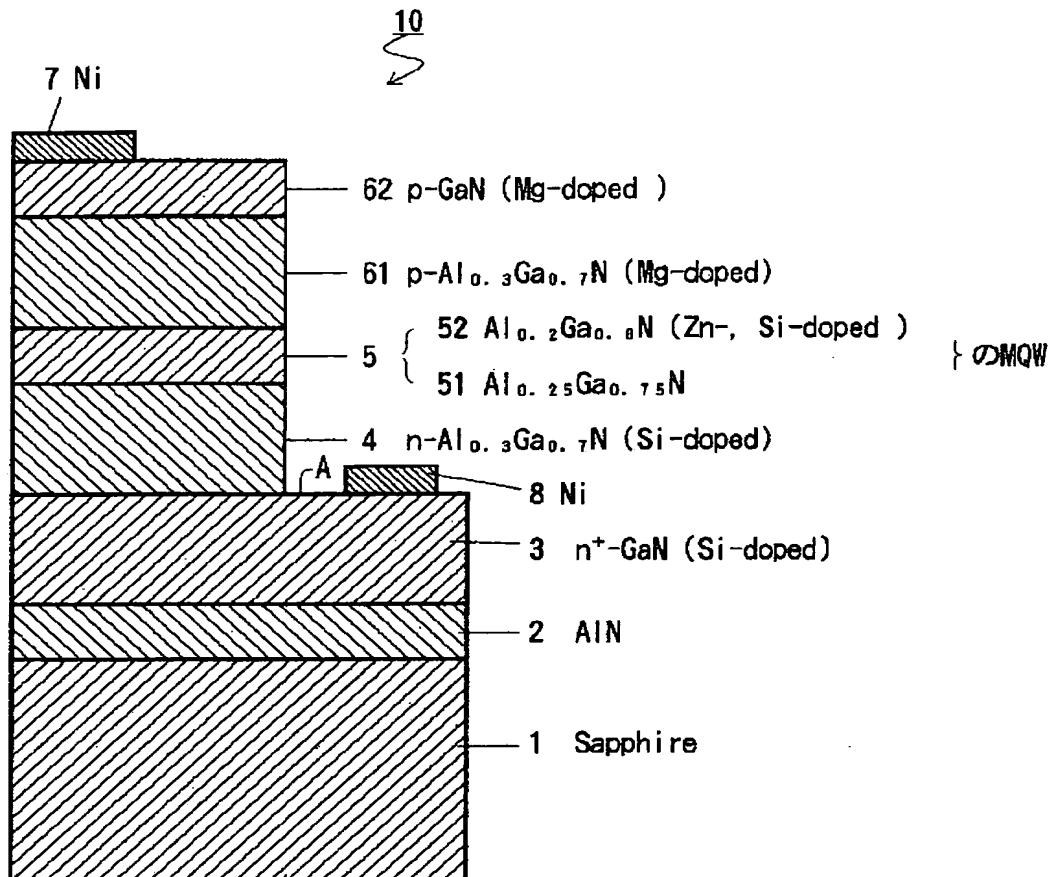
【図12】



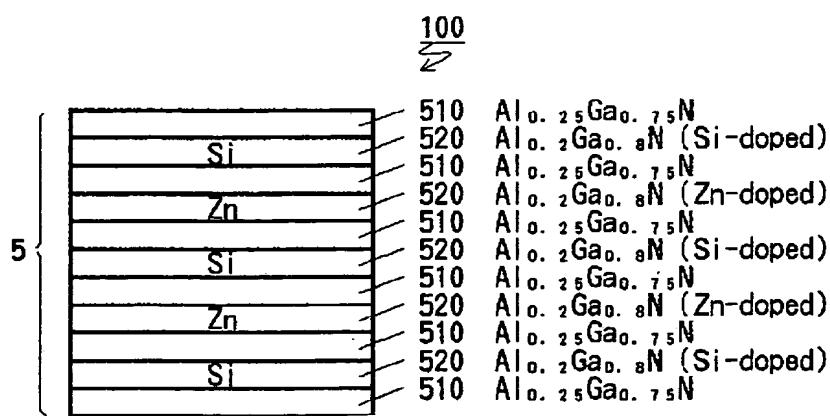
【図13】



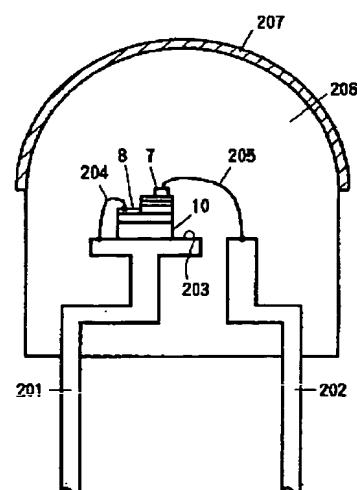
【図1】



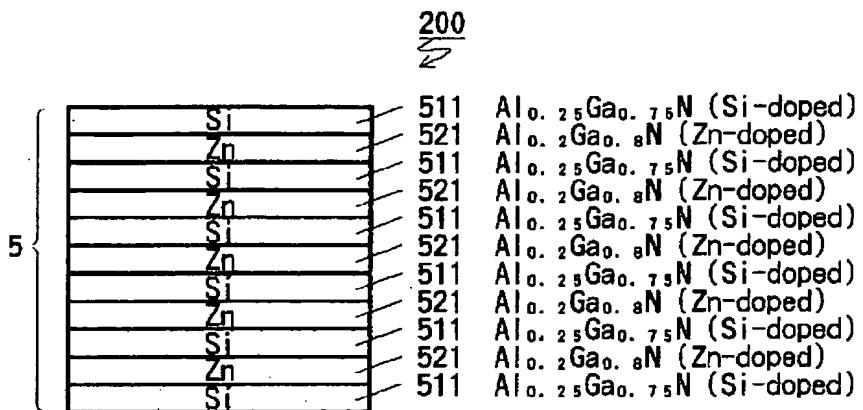
【図6】



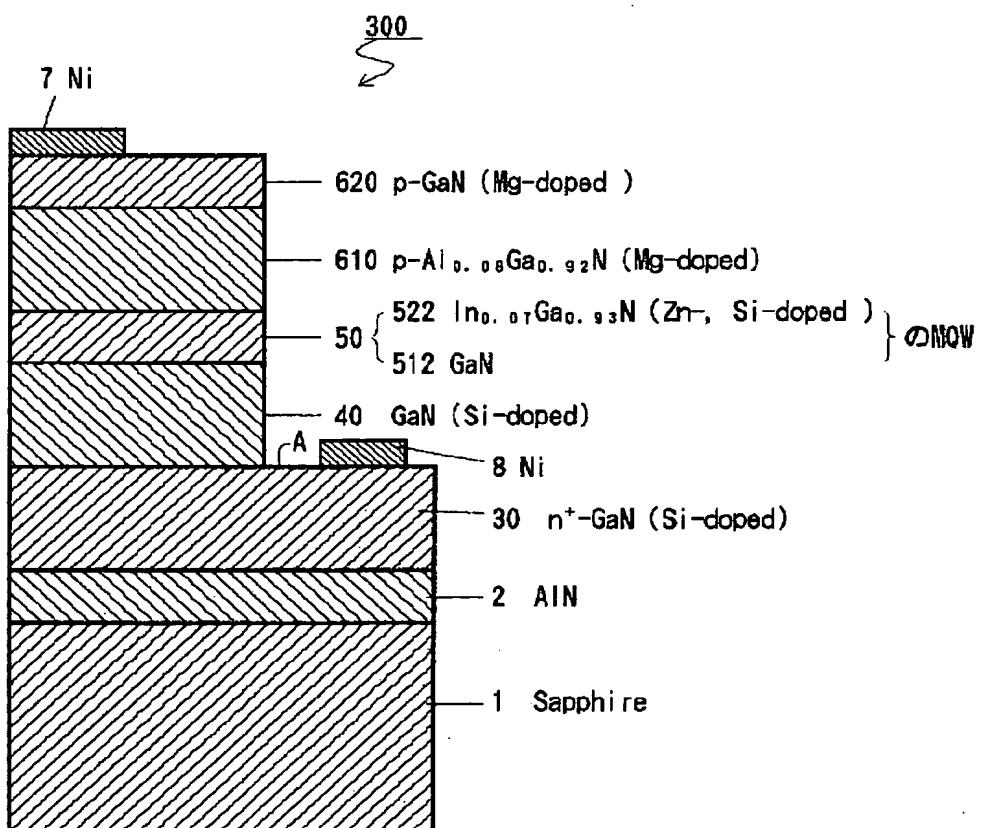
【図10】



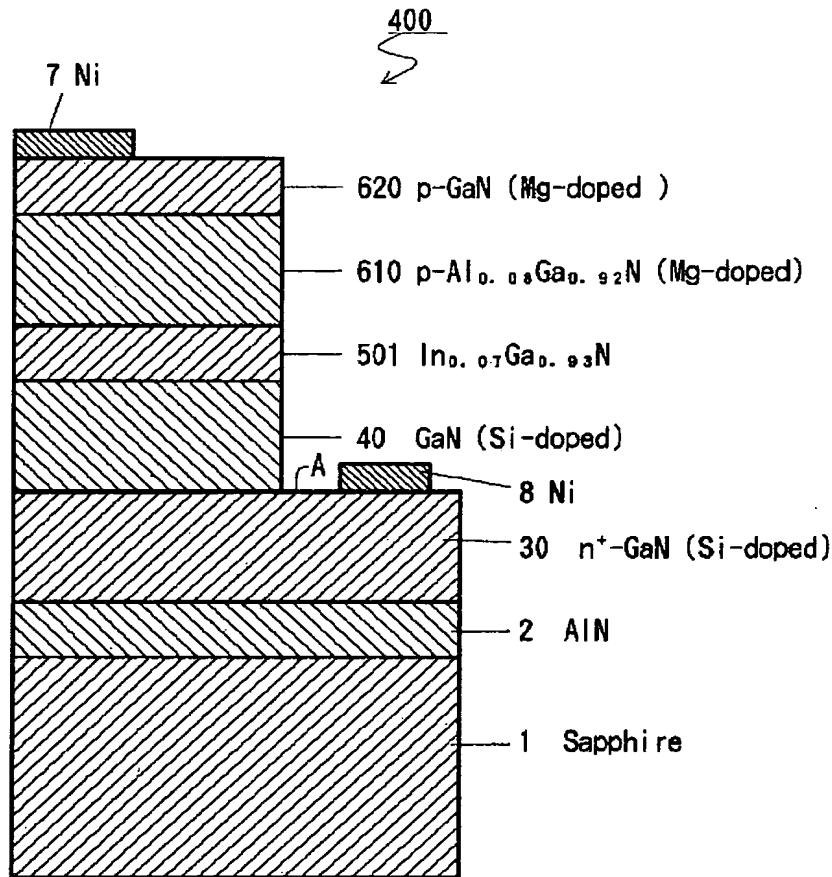
【図7】



【図8】



【図9】




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フロントページの続き

(72)発明者 浅見 慎也

愛知県西春日井郡春日町大字落合字長畑1

番地 豊田合成株式会社内

(72)発明者 小池 正好

愛知県西春日井郡春日町大字落合字長畑1

番地 豊田合成株式会社内

(72)発明者 赤崎 勇

愛知県名古屋市西区浄心1丁目1番38-

805

(72)発明者 天野 浩

愛知県名古屋市名東区山の手2丁目104

宝マンション山の手508号

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